Effect of foaming parameters on the pore size

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Abstract

The effect of foaming temperature, heating rate and external pressure on the density and pore structure of foamed samples has been investigated. The pore structure was evaluated by computer image analysis. It has been shown that the number of pores, their size and orientation can be effectively controlled by a proper choice of the foaming parameters.

Experimental results and discussion

The cylindrical samples with the diameter of 40 mm and height of 51 mm were foamed according to PM-route [1] in a special set-up (Fig. 1) which allows the independent variation of some process parameters keeping other parameters constant. The powdered foamable precursor (50 g) made of two typical aluminium alloys, AlSi12 and AlMg1Si0.6 was used.

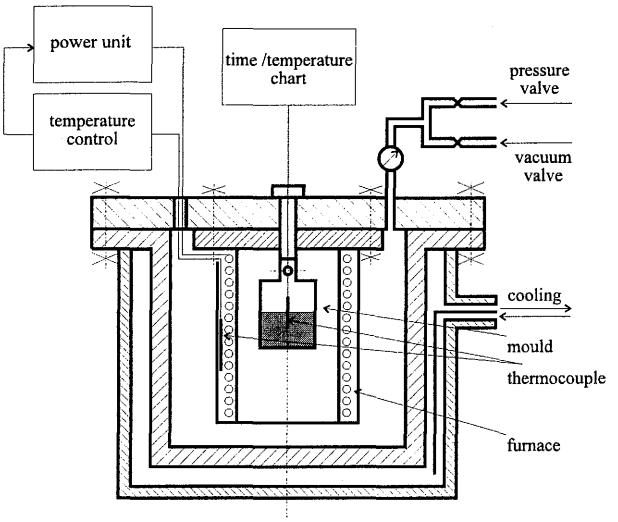


Fig. 1: Foaming equipment (autoclave) for the study of the effect of foaming parameters

The pore structure was evaluated by computer image analysis of vertical cross sections of the foamed samples. Following structural parameters were determined:

- square fraction of the pore walls in the selected area (local density of the foam - 2D)
- number of pores (micropores were neglected) - N
- mean pore size in the selected area - S_{ave}
- shape of the pores (the aspect ratio between minor and major axis of an equivalent ellipse)
- pore orientation (the angle between the major axis of the pore and the vertical direction)

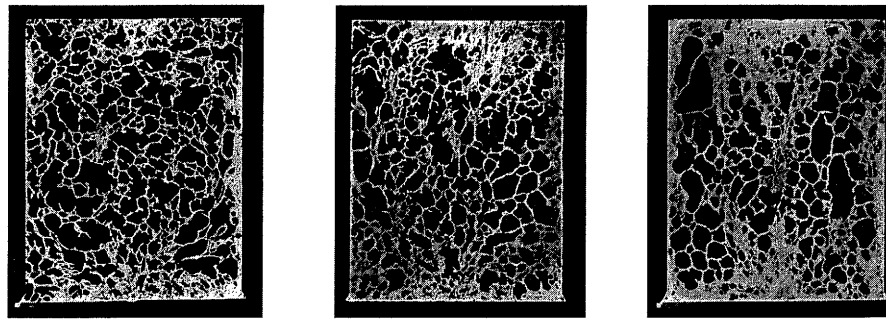
The significant expansion of the precursor takes place predominantly above the solidus temperature of the matrix [2]. The volume of the precursor increases almost 8 times in comparison with its original size until the equilibrium of the gas pressure in pores, surface tension of the alloy and the outer pressure is achieved. If a foaming process still continues the

strongly oxidised walls of the outer pores get thinner and lose their stability. Broken pore walls enable the leakage of the released gas leading finally to the successive collapse of the foam. Foaming parameters that besides the chemical composition of a matrix substantially affect the structure of the foam include:

- maximum temperature of the foam - T_{max}
- heating time until the maximum temperature is achieved - t_f
- period in which the foam is in liquid or semisolid state (above solidus of the matrix) - Δt
- external pressure - p

The effect of the foaming temperature, time and external pressure on the structure of the foam prepared from the same precursor is shown in Figs. 2 - 4. It has been observed that the too low heating rate leads to an extensive oxidation of the precursor surface which improves the resistance towards the foam expansion and increases the final density of the foam (see Fig. 2). Long period in which the foam is liquid or semisolid gives an opportunity for the so called drainage, i.e. flow of the molten metal from the cell-walls into the cell-edges. The extensive drainage results in a coarsening of the pores; pore walls become thicker and vertically oriented (Fig. 2b). The increase of the foaming rate effectively eliminates the effect of these factors; the resultant density becomes lower and the homogeneity of the foam structure is improved.

a.



heating time:	**420 s**	**790 s**	**1120 s**
density:	0.508 g.cm^{-3}	0.513 g.cm^{-3}	0.759 g.cm^{-3}
S_{ave}:	16.02 mm^2	17.08 mm^2	16.85 mm^2
N:	440	463	401

b.

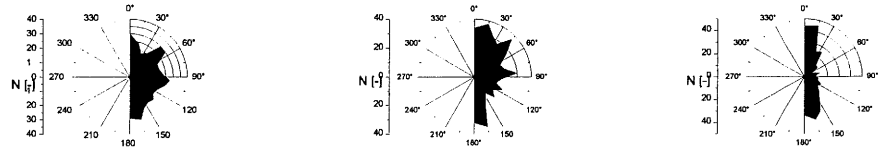
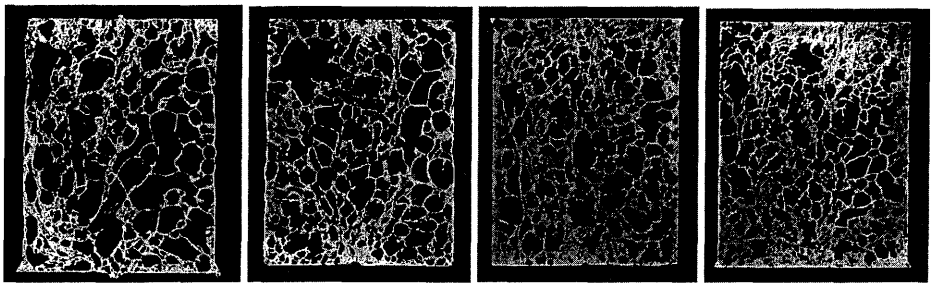


Fig. 2: Effect of the heating time on the structure (a) and pore orientation (b) of AlSi12-foam (atmospheric pressure, samples ϕ 40 x 51 mm, T_{max} = 580°C)

Due to the lower viscosity of the alloy at higher foaming temperatures the effect of drainage becomes more apparent, what leads to the marked increase of the pore size and to the inhomogeneities in the resultant structure (see Fig. 3).

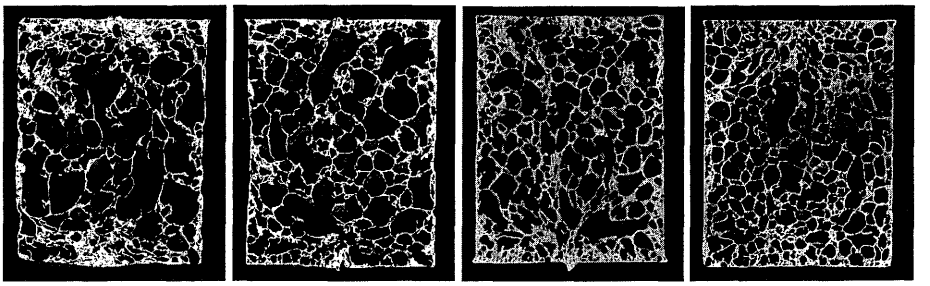
The expansion of pores is ceased when the equilibrium has been achieved between the internal gas pressure in pores and the surface tension of the alloy supported by the external pressure applied onto the sample. Therefore the size of pores can be to a certain degree

influenced via the control of the external pressure (see Fig. 4).

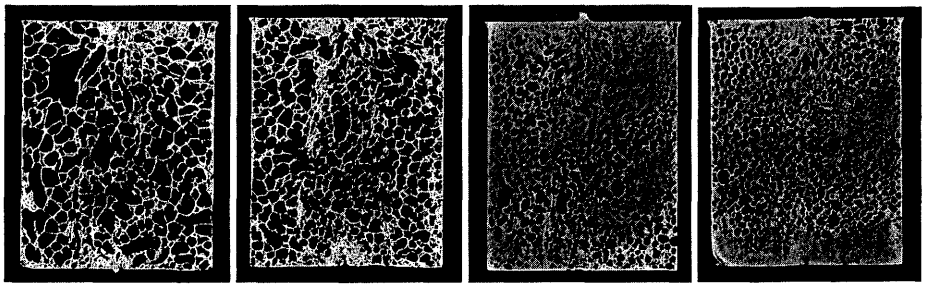


T_{max}:	**625°C**	**610°C**	**600°C**	**580°C**
density:	0.344 g.cm^{-3}	0.352 g.cm^{-3}	0.464 g.cm^{-3}	0.513 g.cm^{-3}
S_{ave}:	28.36 mm^2	28.31 mm^2	19.42 mm^2	17.08 mm^2
N:	304	344	380	463

Fig. 3: Effect of the maximum foaming temperature on the structure of AlSi12 - foam (atmospheric pressure, constant average heating rate: 46 ± 2°C/min)



p:	**0.05 MPa**	**0.07 MPa**	**0.1 MPa**	**0.16 MPa**
T_{max}:	**600 °C**	**590 °C**	**620 °C**	**620 °C**
density:	0.378 g.cm^{-3}	0.385 g.cm^{-3}	0.374 g.cm^{-3}	0.373 g.cm^{-3}
S_{ave}:	31.69 mm^2	29.80 mm^2	11.61 mm^2	11.77 mm^2
N:	356	43	468	498



p:	**0.2 MPa**	**0.25 MPa**	**0.3 MPa**	**0.4 MPa**
T_{max}:	**625 °C**	**625 °C**	**625 °C**	**630 °C**
density:	0.373 g.cm^{-3}	0.423 g.cm^{-3}	0.514 g.cm^{-3}	0.558 g.cm^{-3}
S_{ave}:	12.12 mm^2	6.72 mm^2	3.99 mm^2	2.79 mm^2
N:	524	666	807	945

Fig. 4: Effect of the external pressure *p* on the structure of AlSi12 - foam (average heating rate 50 ± 4°C/min)

The increase of the external pressure results in the decrease of the resultant pore size whereas the number of pores grows. Higher pressures can even completely inhibit the growth of pores. The uniformity of the pore structure can be significantly improved in this way. Application of lower external pressure or vacuum leads to higher pore size with relatively thick pore walls. The effect of the external pressure on the pore size is different for particular alloy, due to different surface tensions and viscosity. The structure of AlSi12 alloys can be effectively influenced by pressures ranging from 0.05 to 0.45 MPa, in the case of wrought alloys it is the range of 0.03 to 0.3 MPa (see Fig. 5). The effect of the external pressure can be to some extent balanced by increasing a pressure inside the pores, e.g. using higher amount of the foaming agent. The external pressure affects significantly also foaming temperature; viscosity of the molten matrix must be reduced by increasing of the foaming temperature to achieve the same foam density at higher external pressures.

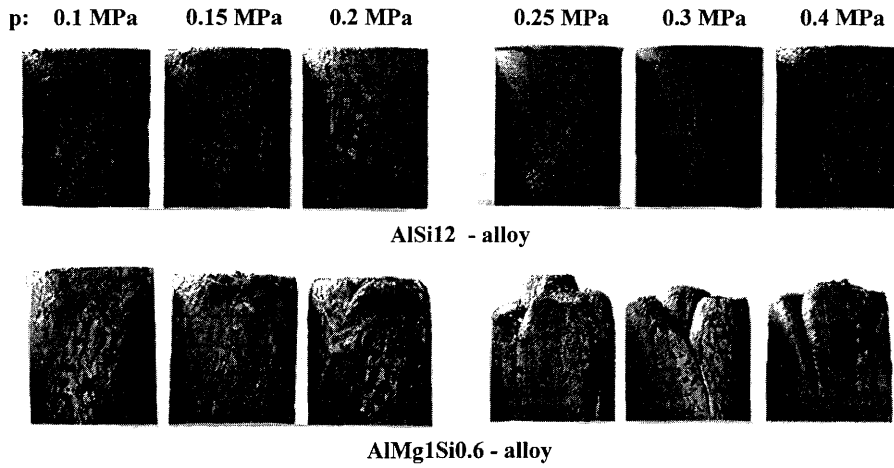


Fig. 5: Effect of matrix composition on the foaming process under external pressure *p*.

Computer methods for the evaluation of the structure have shown, that the size and apparent diameter distributions in aluminium foam cannot be characterised by a normal (Gaussian) distribution. In other words, there does not exit any typical pore size or pore diameter. The shape of pores is irregular with the aspect ratio value most often in the range [0.5,0.8]. Nearly all samples exhibit the orientation of pores along the vertical direction (effect of the gravitation force and of the precursor arrangement). Only rapidly foamed samples (e.g. first sample in Fig. 2) can be evaluated as isotropic without a significant directional orientation.

Conclusions

It has been shown, that the structure of aluminium foam is strongly affected by the drainage of liquid aluminium from the pore walls into the pore edges. The extensive drainage leads to the increase of the pore size, reduction of the pore number and vertical orientation of the pores. The size of pores can be to a certain degree influenced via the control of the external pressure.

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REFERENCES

[1] B.C. Allen, US Patent 3 087 807 (1963)

[2] J. Banhart, P.Weigand, Proc. Metal Foam Symposium, Eds: J.Banhart, H.Eifert, MIT-Publishing Bremen (1997), p. 13